A SYSTEMATIC METHODOLOGY FOR THE VIRTUAL RECONSTRUCTION OF OPEN-CELL FOAMS

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Abstract

In this contribution, we propose a procedure suitable to generate foam geometries to be employed for CFD simulations without using time-consuming image analysis. Based on easily accessible morphological properties, the methodology is able to reconstruct the random and tridimensional foam matrix by accounting also for the strut variable cross-section and the solid clustering at nodes. The geometrical properties, i.e. specific surface area and void fraction, as well as the pressure drop are reproduced with good agreement with experimental data. The so generated foam structures can be used in CFD numerical tools even to carry out parametric analysis of the foam geometrical properties. On a more general basis, the reconstructed foams can be exploited to investigate heat and mass transport phenomena, enabling a detailed analysis and understanding of the experimental evidences.

Keywords

Foams, CFD, Numerical Simulations

Introduction

Open cell foams – cellular materials made of interconnected solid struts that enclose void regions – have recently received a growing attention as innovative catalyst supports. High specific surface area, low density and high permeability to the fluid flow are the main characteristics of foams. These features make foams very attractive as enhanced catalyst carriers (Twigg and Richardson, 2007).

The understanding of the transport phenomena occurring inside these structures, however, is still very poor. Actually, correlations proposed in the open literature have a narrow range of applicability and strongly depend on the particular foams typology investigated. Indeed, Edouard found that the deviation between the predicted and experimental values might be up to 100 % (Edouard et al., 2008), posing a serious issue in the prediction of foam properties. Despite the considerable potential, this scenario is hampering a large-scale industrial application of open cell foams as catalyst supports. Therefore, a fundamental analysis of open cell foams is required to investigate their properties and behavior. In this respect, Computational Fluid Dynamics (CFD) is a valuable tool to improve the understanding of open cell foams, being able to take into account the random tridimensional geometry and to offer a deep insight in the complex flow field. This analysis requires the accurate description of the foam microstructural geometry, which is not an easily accessible information. Actually, the reconstruction of the foam geometry is carried out by means of micro-computed tomography (μCT) or magnetic resonance imaging (MRI). These expensive and time-consuming methods enable the reproduction of a unique portion of the sample that might be not representative of foam features.

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To overcome these problems, the aim of this work is the development of an automatic numerical procedure able to model a realistic random foam structure to be used for CFD simulations. This methodology is based on easily accessible morphological parameters, without requiring any data from image analysis.

Results

Our approach is based on the following workflow: first, a random bed of spheres of fixed size is packed using a Discrete Element Method (DEM); then, each sphere is substituted by a polyhedral unit cell whose features relay on the geometrical characteristics of real foams. Last, the vertices of the cells are moved to ensure a continuous solid matrix by means of the overlap among struts. A strut profile that takes into account both the shape of cross-section and the solid clustering at nodes is proposed. The resulting foam structure, obtained exploiting the porosity, cell diameter and strut thickness, resembles the real foam geometry and can be easily simulated by CFD.

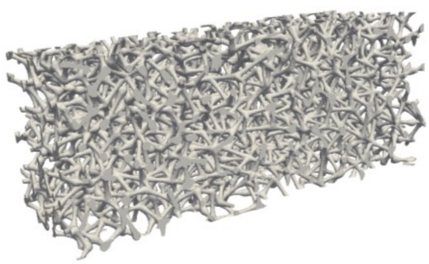

Figure 1. An example of a reconstruction of real foam structure

An example of foam reconstructed according to our procedure is shown in Figure 1. The microstructure resembles the real foam geometry in terms of random pore distribution and fully interconnected solid matrix. In facts, several foam samples have been generated to validate the procedure. The geometrical properties of the generated foams have been compared with tomographic data to validate the methodology (Bianchi et al., 2012). The specific surface area is a significant parameter in the description of the transport properties.

Table 1. Comparison between specific surface area of reconstructed foams and estimate from tomography of real foams

	ε [−]	$S_{V,rec}$ [m^{-1}]	$S_{V,exp}$ [m^{-1}]
Sample A	0.898	697	649
Sample B	0.891	1119	1050

The deviation of the specific surface area between virtual foams and experimental data are less than 7.5 %, as reported in Table 1. Moreover, pressure drop simulations have been carried out to investigate the flow field established inside reconstructed foams. As depicted in Figure 2, reconstructed foams show a good agreement with both experimental data and CFD simulations on μCT scanned samples, which can be assumed to be representative of the real flow field.

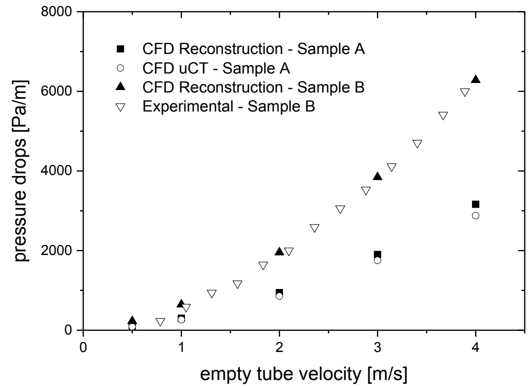

Figure 2. Pressure drop comparison among simulations of reconstructed foams, experimental data and simulation on μCT scanned sample

Conclusions

Based on easily accessible morphological parameters, we have developed a procedure that can generate realistic foam structures to be used for CFD simulations, avoiding time-consuming image analysis.

The methodology is able to reproduce open cell geometries with a promising accordance with real foams for both the specific surface area and the morphological properties. The pressure drop comparison shows the capability of the proposed methodology to generate foam structures that can successfully account also for the complex flow field across their matrices.

On a more general basis, our methodology allows for the investigation of the heat and mass transport phenomena prevailing in foams over a wide range of operating conditions even not accessible during experimental activity. Moreover, the foam generation procedure is an excellent tool for the rational design and the optimization of these structures, enabling a parametric analysis of the foam structural and transport properties.

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